SIM Space Interferometry Mission

A NASA Origins Mission

JPL

Characterization of Picometer Repeatability Displacement Metrology Gauges

Peter G. Halverson, Lawrence S. Azevedo,
Rosemary T. Diaz, Robert E. Spero
Jet Propulsion Laboratory, California Institute of Technology
Pasadena, California 91109 U.S.A.
e-mail: *Peter.Halverson@jpl.nasa.gov*

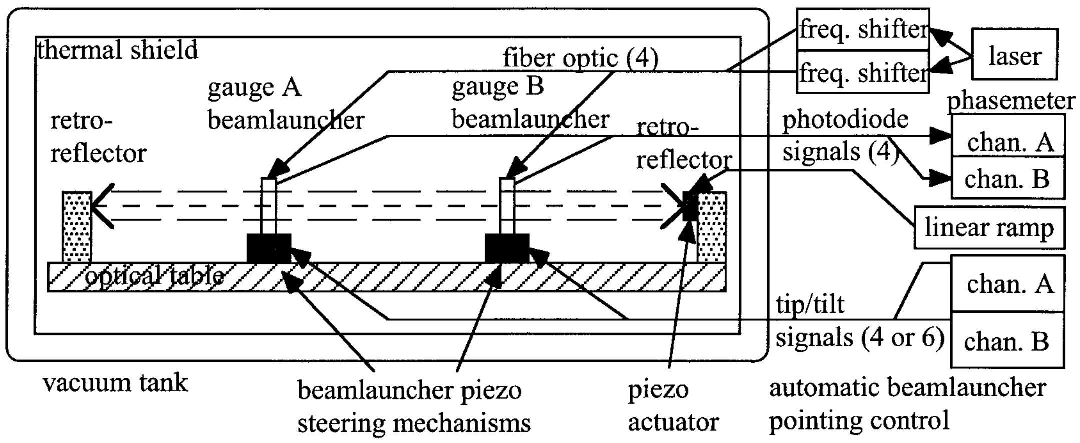
"2 Gauge" Test facility purpose

- Thermal stability testing
  - SIM requires temperature induced drift < 10 pm for 1 milliKelvin.
  - Apply 10 to 100 milliKelvin steps to metrology heads, observe induced distance error.
- Cyclic non-linearity testing
  - SIM requires non-linearity < 10 pm RMS, for small (millimeter) displacements.
  - Dominant effect is cross-talk, either optical or electronic.
  - Apply 0.1 mm linear displacements, observe cyclic non-linearity.
- Other activities:
  - Test automatic metrology head pointing
  - Test cyclic non-linearity reduction techniques.

Test facility schematic

JPL

SIM Space Interferometry Mission



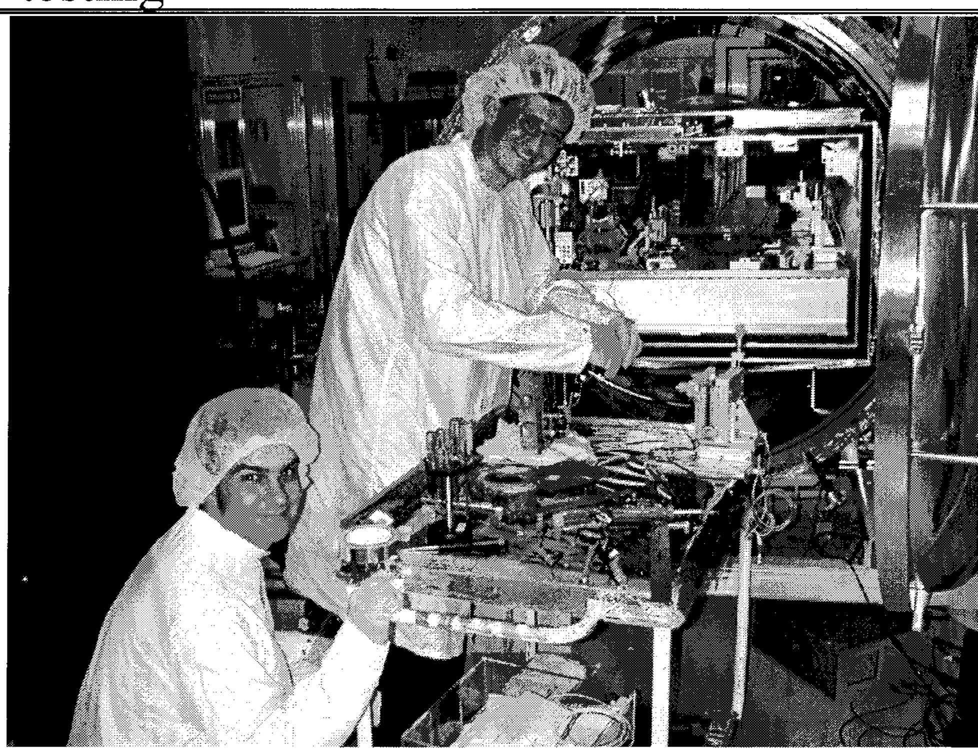
Metrology test facility. 1.3 micron laser output is split and shifted to create a 100 kHz frequency difference, which is seen as a 100 kHz heterodyne signal at the photodiodes. Gauge A's measurement beam (long dash) and gauge B's (short dash) both measure the distance between the retroreflectors. Fold mirrors (not shown) are used to achieve a longer inter-fiducial distance.

A NASA Origins Mission

Installing a metrology head for thermal testing

JPL

SIM Space Interferometry Mission

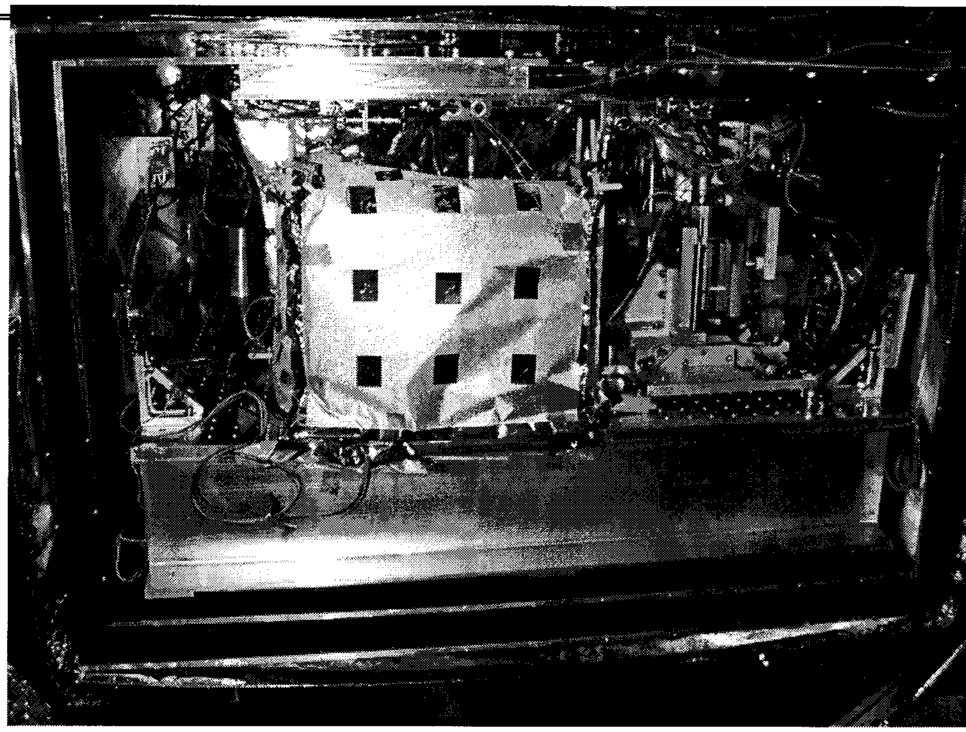


Dorian Valenzuela (JPL) & Mark Scott (LMC) preparing a metrology head.

A NASA Origins Mission

2 gauges, ready for thermal tests

SIM Space Interferometry Mission

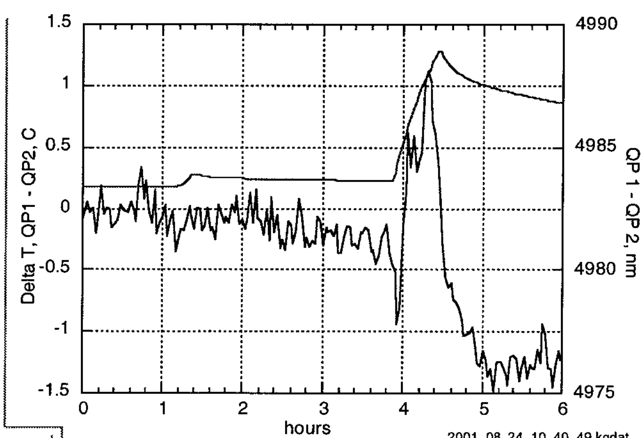


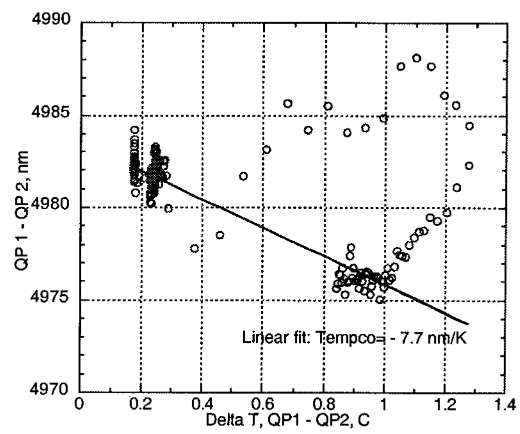
In this setup, a short baseline, ~84 cm is used. Retroreflectors are visible, on left and right.
Multilayer insulation "tent" covers the left gauge, which will be heated.
(Piezo actuator used to piston the retroreflector is missing, not needed for thermal tests.)

A NASA Origins Mission

QP Data Thermal Sensitivity

SIM Space Interferometry Mission

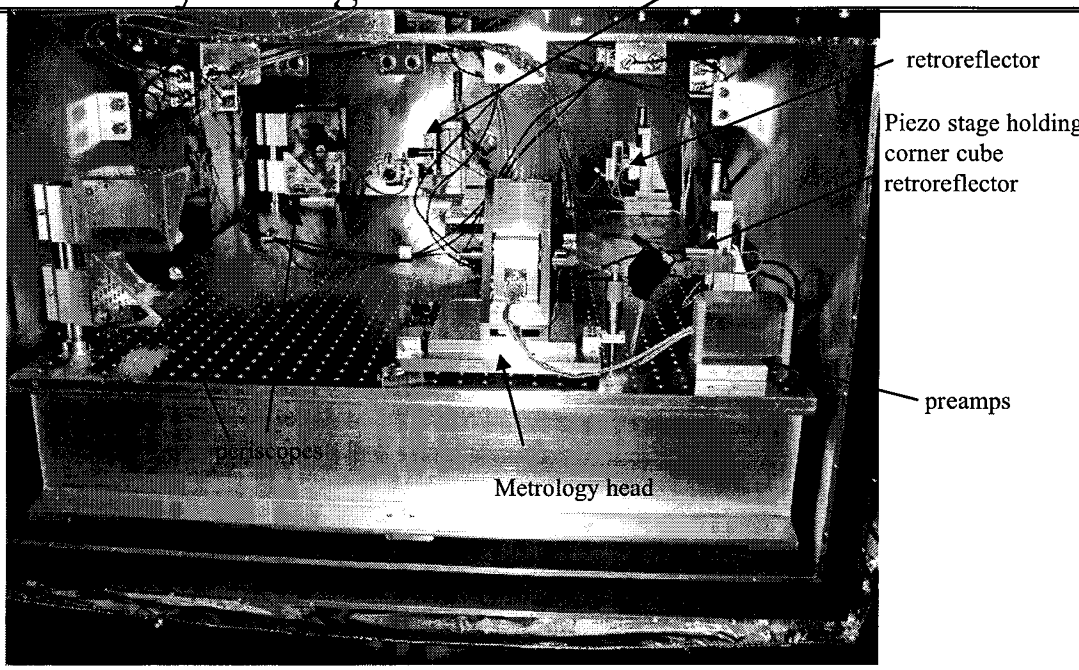




- Measurement in still air. (Alignement stabilities problems encountered in vacuum.)
- 2 temperature steps: 100 mK and 1000 mK. Note that steps were found to induce smaller gradients than the original heat on/off approach.
- Sensitivity to transient gradients, but relative immunity to soak
- Result in air: 7.7 pm/mK
- (QP launcher uses physical beam separation to control cyclic non-linearity.)

A NASA Origins Mission

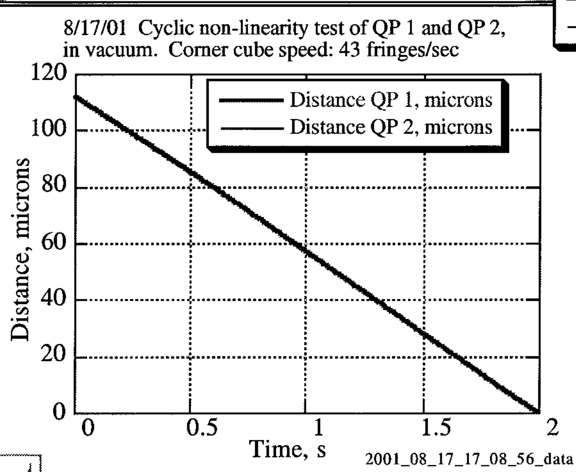
Metrology head ready for cyclic non-linearity testing

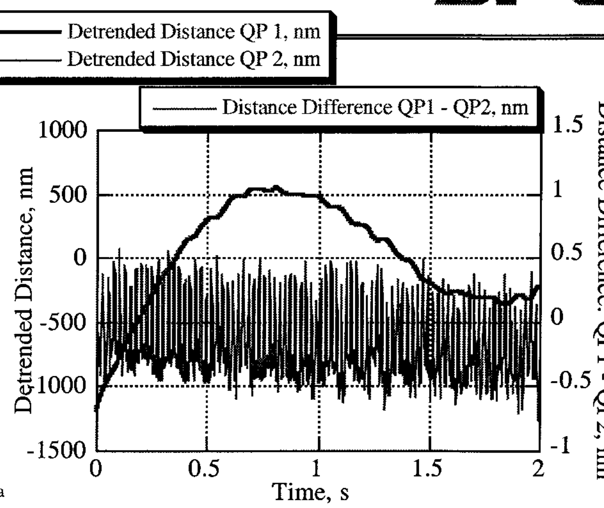


In this picture, a polarizing type metrology head is mounted between retroreflectors, one mounted on a 100 micron stroke PZT driven stage.

A NASA Origins Mission

QP Data, Cyclic Error

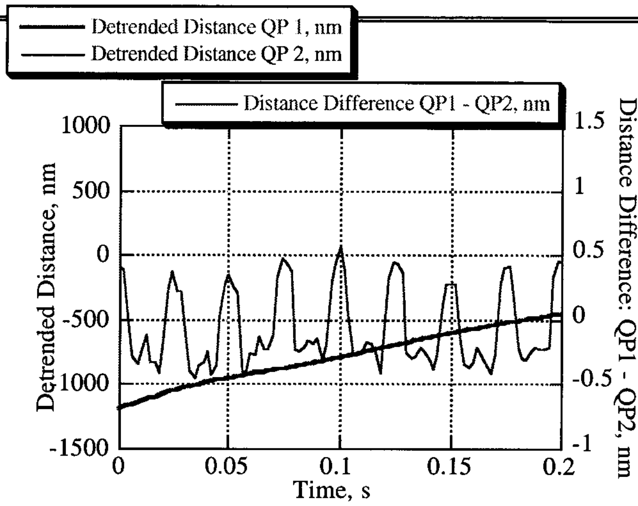




- Left plot shows distance data taken with near-linear sweep of corner-cube PZTstage. (Distance decreases with time. Corner cube scanned over 86 waves in 2 seconds.)
- Right hand plot shows same data, after subtracting a linear fit to the data. Cyclic error is too small to be seen in the individual gauge detrended plot. ("S curve" is due to small, ~1%, non-linearity of PZT. Wiggles in the detrended distance plots are low frequency vibrations.)
- Also shown (in green) is the **difference** between two gauges. (Note 1000x change in scale). Since PZT non-linearity and low frequency vibrations are common-mode and cancel out, the cyclic error is easily seen. However, this data can be misleading as it is the **difference in errors** between the two gauges. (Identical, in-phase cyclic error would not be observable this way.)

A NASA Origins Mission

QP Data, Cyclic Error

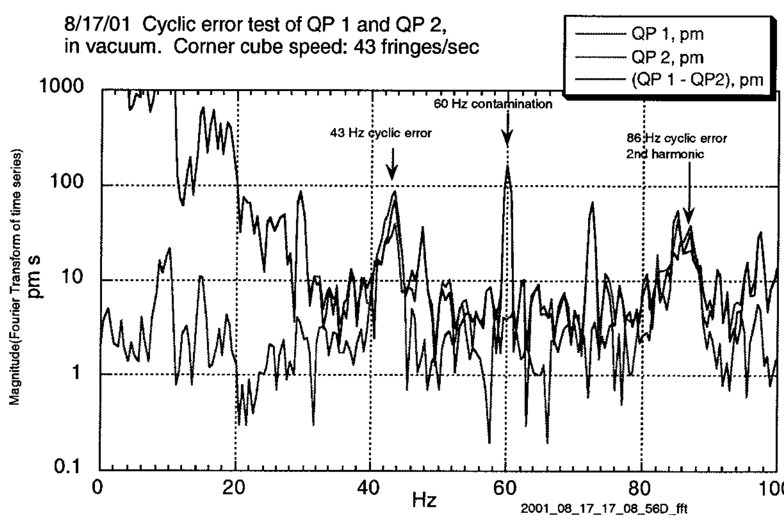


- Same data as before, but with 10x time axis change of scale.
- Note that error is "cyclic" (as expected) but is not a pure sinusoid.
- FFT analysis reveals significant 2nd harmonic. Higher harmonics are negligible.
- 2nd harmonic can be caused by:
  - a) Simultaneous mixing of Ref. beam into Meas. detector and meas. Beam into Ref. detector.
  - b) Electronic cross-talk.

SIM Space Interferometry Mission

A NASA Origins Mission

QP Data, Cyclic Error



- Same data as before, but viewed in time domaine.
- This plot is from single scan. No averaging.
- Corner cube scanned over 86 waves
- Some contamination from motors, resonances in hardware.
- Results, including 2nd harmonic: #1: approximately 57 pm. #2: 98 pm.(RMS)

SIM Space Interferometry Mission

A NASA Origins Mission

Recent results summary

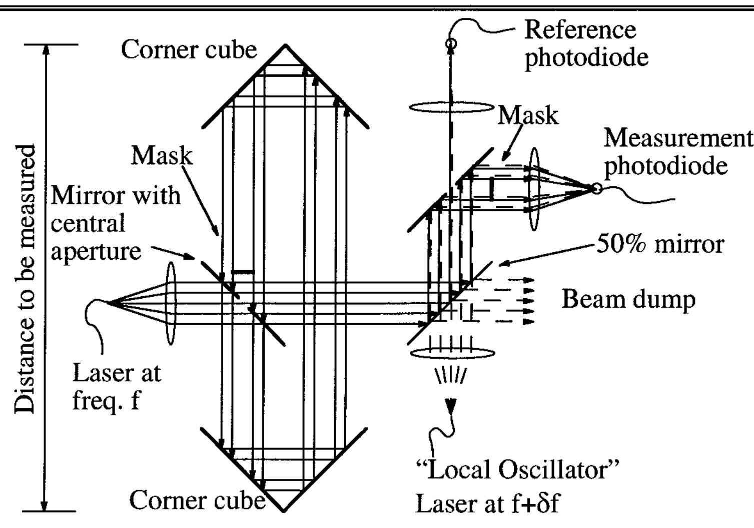
SIM Space Interferometry Mission

	Performance to-date	Probable limiting factor
Thermal stability Non-polarizing metrology optics	8 pm/mK	Mechanical flaws (easily improved)
Thermal stability Polarizing optics	12 pm/mK	Thermal gradients in testing?
Cyclic non-linearity Non-polarizing metrology optics	~90 pm (RMS)	Diffraction Electronic cross-talk (improvements underway)
Cyclic non-linearity Polarizing optics	130 pm	Polarization leakage Noise (Recently improved, new data needed.)
Cyclic non-linearity Polarizing optics & phase modulation	80 pm	Electronic cross-talk. Noise (Recently improved, new data needed.)

A NASA Origins Mission

Non-polarizing displacement metrology head

SIM Space Interferometry Mission



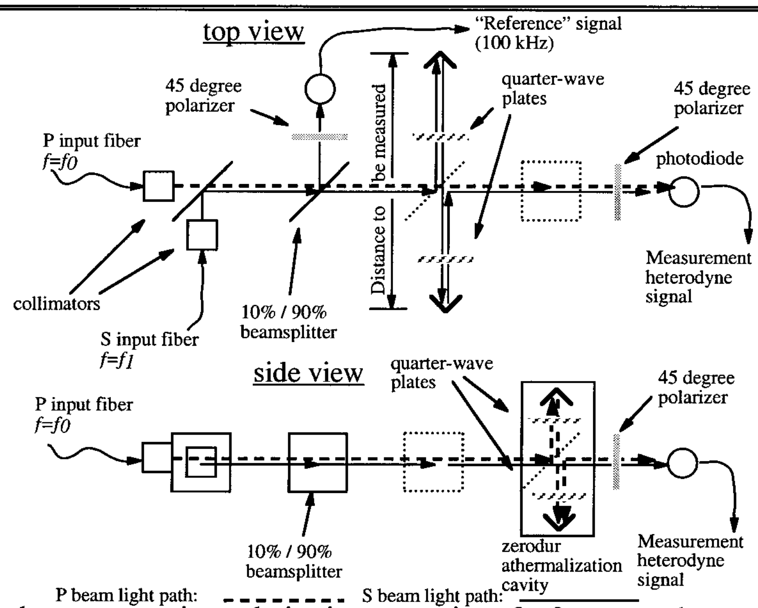
New

Heterodyne metrology gauge using physical separation of reference and measurement beams.

- Reference beam is created by aperture in diagonal mirror (left-hand side), while outer, reflected, portion, is the measurement beam.
- The "local oscillator" beam (dashes) mixes with the ref. and meas. beams and the resulting heterodyne signals are detected by the corresponding photodiodes. Measured distance is $2\lambda\times$ (phase difference).
- Cyclic non-linearity is controlled by masks preventing leakage between beams. Diffraction around masks is a concern.

A NASA Origins Mission

Displacement metrology head using polarization



Metrology gauge using polarization separation of reference and measurement beams.

- Reference beam is P polarized while measurement beam is S.
- A portion of the P and S beams are mixed to form a reference signal. Further, the S beam travels the distance to be measured and then mixed to form a measurement signal. Measured distance is $2\lambda x$ (phase difference between ref. and meas. signals).
- Cyclic non-linearity is mostly caused by P leakage through the first polarizing beam splitter.

SIM Space Interferometry Mission

A NASA Origins Mission